Construction and Consideration of America's Underground Gas Storage

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***Abstract*- As an important part of natural gas market, underground gas storage plays an irreplaceable role in peak shaving and guaranteeing the security of gas supply. Based on investigations and researches on the status of underground gas storage construction in the USA, information about types, numbers, reservoir site layouts, capacity and characteristics of underground gas storages managements in the USA are concluded, combined with the development of natural gas industry in China, suggestions such as optimizing construction layouts of underground gas storages, accelerating the construction pace of underground gas storages and making an early plan for natural gas strategic reserve are given[1].**

Keywords- Natural Gas; Underground Gas Storage; Peak Shaving; Strategic Reserve; America

I. INTRODUCTION

The underground gas storage is aiming to inject gas produced from oil field into underground where it can be conserved. It plays a non-substitutable role in peak shaving and ensuring safety of gas supply. Major countries in natural gas production and consumption regard construction of underground gas storage as a consequential partition of natural gas integration of upstream and downstream. At present, the U.S. has already achieved natural gas strategic reserve by possessing the maximum quantity and capacity of underground gas storages. Underground gas storage in China is in her inception, it would be helpful with reference of the U.S's projection and construction experience.

II. THE GAS STORAGE RESERVIOR CONSTRUCTION AND MANAGEMENT IN THE UNITED STATES

A. The Characteristics of Gas Storage Construction in the United States

The depleted oil-gas reservoir gas storages occupy the largest number of gas storages in the U.S, but the salt cavern underground gas storages develop fastest in recent years. According to the statistics from the EIA, there are 400 underground gas storages in the U.S. in 2007 and 326 of them are the depleted oil-gas reservoir gas storages, occupied 81.5% of the total number. 43 of them are the aquifer underground gas storages account for 10.8% of the total number. 31 of them are the salt deposit or salt cavern underground gas storages account for 7.7% of total number. The depleted oil-gas reservoir storages occupy the largest number of gas storages. They are short in construction cycle, low in investment and operating fees, huge in gas storage capacity and great economic profits, mainly used in seasonal peak shaving. The salt cavern underground gas storage is small in capacity, but it can meet the needs of the daily peak shaving due to its strong maneuverability, fast gas injection and high production speed as well as less cushion gas consumption so that the salt cavern underground gas storages develop fast in recent years. According to the document material[2], the U.S had expanded 47 underground gas storages including 31 salt cavern underground storages from 2004 to 2008.

The underground gas storages are mainly distributed in the central areas of gas consumption and production. In the U.S, the underground gas storages are mainly distributed in gas production areas like the northeast and south where contain the most of the consumers [3], among them about 50% of the underground gas storages are concentrated in the northeast region where the major natural gas is consumed .Underground gas storages are also distributed in the regions with adequate natural gas resources, such as Texas and Louisiana. According to the statistics from the EIA, on September, 18th, 2009, the maximum working volume of all gas storages in U.S is $998.3\times10^8m^3$, the southern production areas and the eastern consumption areas accounting for 86.3% of the total working volume [4].

The U.S met the regular peak shaving and achieved initial strategic reserves of natural gas by increasing gas production in the peak period and increasing gas injection in the trough period. According to table 1, during the peak gas consumption in 2008 (from December to February), in order to meet the stable gas supply, the storage production gas accounts for 25.7%~32.8% of the monthly consumption gas. In addition, most of the working gas can be used as the strategic reserve because most of them are still in the gas storages and only a small proportion of gas was used. For example, in January (the maximum gas production month) of 2008, the proportion of production gas only accounted for 44% of the working gas. The maximum working gas volume of all gas storages in the U.S was $926.5\times10^8m^3$, accounting for 14.1% of the total natural gas consumption volume (6 $572.4\times10^8m^3$) and the strategic reserve days have reached 53 days.

B. The U.S Gas Storage Operating Management

1) The Operating Pattern

In the U.S, underground gas storage operators are as a member of the gas industry chains, they are independent fromthe natural gas developers and the terminal vendors. They take responsibility for gas storage and transportation.

The gas storage operators in the U.S include the interstate pipeline companies,the state pipeline companies, the city gas companies and the independent gas storage operators

The interstate pipeline company. These types of companies mainly adjust the supplement and the peak shaving during their working process by making use of their long distance pipeline. Under this circumstance, The Federal Energy Regulatory Commission developed the regulation requires the interstate pipeline companies open their rest storage capacity to the third parties. Currently, 25 natural gas pipeline companies own 172 natural gas storages, accounting for 55% of the total gas storage volume.

The state pipeline companies and city gas companies. The state pipeline companies also adjust the supplement and peak shaving by making use of their gas pipeline during the working process. The city gas companies transmit natural gas directly from the gas storages to the consumers. Such operators occupy 35% of total gas storage volume.

The independent gas storage operators. According to the law of the U.S, the gas storages can be rented to the third consumers, such as the operators and power plants. With the lifting of more restrictions, these types of operators will occupy more market share in the future. Now the gas capacity of these operators is 10% of the total storage volume.

2) Business scope

According to the gas storages investigation made by Beijing Hua You Oil Company , the business scope of gas storage in the U.S. including the seasonal peak shaving, the gas supply for the peak power stations and the emergent gas supply, "deposit and loan gas" business storage facilities of LNG, etc [5]. Due to the gas storage operators are only responsible for natural gas storage and charge for natural gas storage fees, so that operators have to ensure the safety of operating, and then maximizing the gas storage injection-production cycle times to get more profits.

The direct reasons for the rapid growth of America's underground gas storage are the lifting of the gas storage construction ban and the increase number of gas power plants , but the fundamental cause is the different gas prices in summer and winter, as well as the peak shaving gas price and peak bargaining gas, etc. The existence of different prices prompted gas distributors to store gas in the trough period and sell it in the peak period. By this operation mode, gas storage operators charge natural gas storage fees and natural gas distributors obtain profits of price difference.

III. CHINA'S GAS STORAGE CONSTRUCTION AND COUNTERMEASURES

A. General Situation of Construction

The construction of the underground gas storage in China started late in the 1970s, Daqing oilfield tried to build gas storage by making use of gas reservoir. They built Sartu No.1 underground gas storage and Lamadian gas storage [6]. Among them, Sartu No.1 underground gas storage had been dismantled but the Lamadian gas storage is still in service since it has been completed in 1975. With two expansions in recent years, the total storage capacity of Lamadian underground gas storage has reached $100\times10^4m^3$daily, and the gas injection capacity has reached $1.5\times10^3m^3$ annually, the total capacity reached $25.0\times10^8m^3$.

In the 1990s, China started the comprehensive research of underground gas storage. Dagang gas field is a place nearby Tiangin city. This field used depleted condensate gas reservoirs to build Dagang gas storage system for coping with the Shanxi-Beijing natural gas pipeline and guaranteeing gas supply and peak shaving of Beijing city and Tianjin city. Now, this gas storage system has 6 gas storages. It can meet the needs of $13\times108m^3$'s seasonal peak shaving gas supply and $3400\times10^4m^3$'s daily emergency peak shaving capacity and $1305\times10^4m^3$'s daily gas injection capacity.

In recent years, with the increase consuming proportion of natural gas in energy consumption, CNPC (China National Petroleum Corporation) and Sinopec have strengthened their devotion in planning and constructing on underground gas storages. According to the public reports, CNPC is planning to build 10 gas storage systems with $244\times10^8m^3$'s peak shaving capacity, those gas storage systems are located in the north, northeast and southwest China, Xinjiang province, Yangtze river delta area，etc. In the north China, CNPC and the Beijing municipal government jointly invested in a gas storage project. It has initially formed a long-term strategic planning involved 11 strategic gas storage systems. Among them, the Beijing 58 gas storage systems are predicted to have 6 $000\times10^4m^3/d$ average gas supply capacity after completion, the construction schedule has completed 76%. In the Yangtze river delta, CNPC has been building the underground salt cavern gas storage in Jintan city, Jiangsu province and in Dingyuan city, Anhui province. Among them, Jintan gas storage has basically completed at the end of August 2009. In the northeast China, CNPC plan to build Daqing oil field gas storage, Jilin oilfield gas storage, as well as Liaohe oilfield gas storage. Sinopec also started preliminary research on the construction of gas storage in Shengli oilfield, Zhongyuan oilfiled, Jianghanand oilfield and Jintan oilfield. Now, Jianghan and Jintan gas storages are continuing their preliminary works and planning to store gas around 2011. Jintan gas storage is designed to have effective gas storage for $10\times10^8m^3$. According to the gas peak shaving and storage requirements, Sinopec plan to build it with $9.60\times10^8m^3$'s working gas storage capacity by the end of 2020.

In addition, according to the relevant schedule, Chengdu will build its first large size underground gas storage with $2\times10^8m^3$'s initial scale in Longquan district and Luodai district. Chongqing city also plans to build an underground gas storage with $8\times10^8m^3$gas storage capacity in phase I and $20\times10^8m^3$gas storage capacity after completion of phase II.

B. The Countermeasures for Acceleration of Underground Gas Storage Construction in China

In recent years, the underground gas storage construction in China has been developed rapidly, but it still in its infancy comparing with the U.S, the construction of gas storage still lags behind the rapid development of natural gas industry. With reference with American gas storage's construction and operation, China should devote great efforts to the construction of underground gas storage in following areas:

TABLE I. THE MONTHLY PROPORTION OF GAS PRODUCTION TO CONSUMPTION IN 2008

Month	1	2	3	4	5	6	7	8	9	10	11	12
Gas production/10^3m^3	252.5	183.7	99.2	29.9	15.9	22.8	25.0	25.9	27.7	25.9	71.0	174.1
consumption/10^3m^3	770.1	703.8	641.4	513.6	446.2	455.2	484.1	477.7	414.0	462.7	426.6	676.9
proportion	32.8%	26.1%	15.5%	5.8%	3.6%	5.0%	5.2%	5.4%	6.7%	5.6%	13.5%	25.7%

Data resource: EIA

Start to develop strategic reserve of natural gas as soon as possible by increasing the number of gas storages and enhancing their storage capacity as well as implementing gas storages for seasonal peak shaving. According to the forecast from State Development and Reform Commission, the demand of natural gas in energy consumption will reach 10%, the total consumption volume will reach $2000\times10^8m^3$and the import capacity will reach $800\times10^8m^3$ by the end of 2020.

Optimize the new gas storage site in those large consumption areas including Sichuan, Chongqing, the eastern China and Guangdong, etc. And increasing construction strengths of underground gas storages guarantee gas supply downstream. Over the years, the natural gas consumption data shows that Sichuan is the largest gas consumption province followed by Jiangsu and Beijing. However, the major projects and construction of underground gas storages in China are mainly concentrated around Beijing, which can only meet seasonal peak shaving of the Beijing-Tianjin region. Now, in those largest gas consumption regions like Sichuan , Chongqing and those fast gas consumption growth regions like coastal areas of China, only Jintian gas storage meets the goal of gas reserve. Other regions are still in planning phase, and are small in numbers and scales. There are plenty salt caverns in Jiangsu and Anhui province, therefore we should make full use of the terrain and find other proper formation to build adequate gas storages to ensure natural gas supply of these areas. According to the estimate from experts, strategic reserve will achieve (200~250) $\times10^8m^3$ [7] for guaranteeing the security of gas supply. With the development of economy, China's dependence on foreign natural gas will gradually improve which is a real problem encountered during the "China's 12th five-year plan". A large number of oil and gas reservoir structures in the northeast and northwest China, and there are relatively plenty of salt caverns underground gas storages in the southwest of China, thus those regions have innate advantages to build underground gas storage.

Optimize and operate depleted oil-gas reservoir resources in eastern China and start the preliminary work. With the ratio of natural gas consumption increasing in China's total energy consumption, the domestic gas price will reach the international standard so that the implementation of gas price difference is imperative. By then, with the process of construction and operation of gas storage, we can guarantee the safety of gas supply as well as getting great profit.

The eastern area of China is the core consumption market. There are many oilfields with great geographical position, such as Zhongyuan oilfield, Shengli oil-field and Jianghan oil. Depleted oil and gas reservoirs in those areas should be fully used to start the preliminary work of gas storage management.

IV. THE FUTURE DEMAND OF CHINA'S UNDERGROUND GAS STORAGE

Natural gas market demand shows rapid growth trend, so the domestic gas supply gap continued to increase. With the domestic natural gas infrastructure's ceaseless complete and the development of economy, it is expected that in 2015 the national natural gas demand will reach 2350×10^8 m^3 ,and upon the year of 2020 it will amount to $3000 \sim 3500 \times 10^8$ m^3 , in 2030 it will reach 5000×10^8 m^3.Because domestic natural gas production cannot meet consumer's demand, for the goal of protection of domestic natural gas supply, we need a large number of foreign imports of natural gas. According to the forecast, the domestic natural gas imports will increase from about 200×10^8 m^3 in 2010 to 1360×10^8 m^3 in 2020 and 2100×10^8 m^3 in 2030. The natural gas import dependency will increase year by year and the degree of dependence on foreign natural gas in 2020 will exceed 50%.

Adjustment and strategic reserve requirements determine the huge demand of natural gas storage. It is expected that by 2020 China's dependence on foreign natural gas will exceed 50%,and according to lessons from foreign countries' experience, if a country's natural gas imports occupy more than 50%, the volume of underground gas storage working gas will reach about 15% of the volume of natural gas consumption. Under this circumstance, suppose that in 2020 the domestic natural gas consumption is 3500×10^8 m^3, so the peaking capacity will reach 525×10^8 m^3 scale. And as China's natural gas external dependence degree rise ceaselessly, natural gas imports will continue to grow, disruption risk of gas supply will be bigger, therefore China should appropriately consider strategic storage requirements. Chinese imports of natural gas mainly comes from Middle Asia, Russia and shipping LNG from other countries, it should be considered near in the gas inlet channel or domestic long distance natural gas pipeline network center region to construct national strategic storage of natural gas. In 2020, according to goal of natural gas strategic reserves reached 30d's natural gas import and in 2030 natural gas strategic storage of natural gas to 60d's import target, It can be estimated in 2020 natural gas strategic storage is 110×10^8 m^3 and in 2030 the natural gas strategic reserves is 350×10^8 m^3.To sum up regulation and strategic storage requirements, in 2020 the volume of working gas of underground gas storage is $650 \times 10^8m^3$ and in 2030 working gas volume should be 1100×10^8 m^3.

Natural gas consumption structure gradually becomes diverse and the proportion of city gas peak-shaving is increasing. Before 2000, gas is the main fuel of chemical and

industrial field, in 1996, this main consumption accounted for about 82% of the total gas consumption, but this demand of consumption structure on peak-shaving is not very urgent. In recent years, demand of city gas consumption and natural gas electronic power plants consumption is proportional rise, China's natural gas market gradually formed a city gas, industrial fuel, natural gas, natural gas structure which is relatively balanced, while the city gas consumption and natural gas electronic power plants on peak-shaving load demand is big, which needs to build enough load supporting implementation, especially in order to meet the demand of underground gas storage.

With the massive exploit of coal bed methane and shale gas, the construction of underground gas storage reservoir has been put forward to higher requirements. Present China are on large-scale development and utilization of unconventional natural gas, especially shale gas, coal-bed gas and tight gas, it is expected that by 2020, coal bed gas production in China will reach $500 \times 10^8 m^3$, shale gas production will reach 800×10^8 m^3 and coal gas production will exceed 100×10^8 m^3.Due to the unconventional natural gas's low output of a single well so its regulating function is weak, therefore it is necessary to have natural gas peak-shaving facilities for the development and utilization of these resources.

The balanced pressure and gas of long distance backbone network accelerates the growth of demand of underground gas storage peak-shaving. According to other countries experience, 5 to 10 years after accomplishment of long distance backbone network formation is the underground gas storage demand rapid growth phase, after natural gas consumption reaching to a peak point, underground gas storage demand will show a steady growth trend. At present, China's consumption of natural gas is still in the rapid growth phase and peak demand can still be adjusted through the new pipeline which does not reach full load running point. The demand for underground gas storage is more urgent when China's long distance pipeline is completed and the basic operation is at full load by 2020.

To sum up, as a result of natural gas consumption structure has been changed, peak-shaving and natural gas strategic storage requirements' development, unconventional natural gas utilization and many other factors, China's underground gas storage grow rapidly, which is expected until 2020 the work of underground gas storage gas demand will reach 650×10^8 m^3 and in 2030 it will reach 1100×10^8 m^3.

V. China gas storage field bottleneck problem

Underground gas storage construction lags than natural gas pipeline construction. Since twenty-first Century, China's rate of long distance natural gas pipeline construction is unprecedented and growth rate of gas supply is very fast, but the construction of underground gas storage is often after the completion of natural gas pipeline construction, and the construction cycle needs 5～8a's time, leading that the construction of underground gas storage speed cannot follow the speed of natural gas pipeline construction which cannot meet the growth needs, peak-shaving demands.

The methods of natural gas pipeline manipulation and gas peak-shaving control is weak and it simply cannot satisfy the needs of gas in downstream market. Due to the vast territory of China, natural gas resource distributes widely and natural gas resources are mainly concentrated in the western region of China. But the gas consumption market is mainly concentrated in the eastern and southern regions, also all long distance natural gas pipeline exceeds 1 000km, moreover long distance natural gas pipeline called "West second-line" is over 3 000km. So making use of the upstream gas field and natural gas pipeline to satisfy the downstream market of natural gas peak-shaving is not possible, meanwhile the operation is difficult with poor economic benefit.

The design of underground gas storage is inadaptable with construction technology and complex reservoir geological condition in China. As to the gas reservoir which has been incorporated into the building target, it is buried deeply and has low permeability also seriously watered out. All of these problems are waiting for a solution. Eastern and southern region of China is characteristic of layered distribution of salt, interlayer, small thickness, difficulty of cavity making. And these problems are also faced in the international construction of salt cavern gas storage. While there is no precedent experience for aquifer and oil-reservoir construction in China, this kind of geological selection standard of underground gas storage are still groping.

VI. Chinese development faces the challenge of underground gas storage

A. Resource Challenge

East China oil and gas reservoir has been basically brought into underground gas storage future constructing place. Due to complicated geological conditions in eastern region, finding the right place to build underground gas storage requires a lot of work. The oil and gas exploration in southern region did not make any break through, which cannot be used as oil gas reservoir and the water reservoir exploration task is very hard. The single average underground working gas storage volume around the world is 5 × 108 m3. According to the average level of the world, if we need a new 500 × 108 m3 volume of working gas then we need to build 100 new underground gas storage and need to find, search, evaluation about 300 traps.

B. Technical Challenges

Other countries like America, Russia have formed a set of mature underground gas storage system and process of evaluation, selection, construction and management technology, yet in these areas China has just started so the technical system is not mature.

Compared to foreign underground gas storage construction, in China, the construction object is rather complicated, for instance, it is a considerable challenge how to build underground gas storage in low permeability, ultra deep, complex geological conditions of oil gas water system. From the current construction target, the depth of underground oil storage reservoir is generally deep, almost more than 2 000m, the deepest reaches 5 000m. The reservoir physical property is poor, the permeability of partially area is only a few millidarcy and some targets have been flooded, so the

expansion of capacity is very difficult. In addition most of these reservoirs are development well from 1960s to 1970s, so the well condition is complex and the effort of processing or repair is difficult. At the same time, many gas reservoir depletion rates is high, pressure coefficient is low, drilling, completion, cementing is difficult.

VII. THE FUTURE DEMAND AND THE MAIN DRIVER OF GROWTH AROUND THE WORLD

With the growth of natural gas consumption demand, the demand of underground gas storage will grow too. According to the IGU predictiction, until 2020 the global demand for natural gas will from 3×10^{12} m^3 in 2005 to 3.7×10^{12} m^3, and in 2030 it will increase to 4.5×10^{12} m^3.At the same time, it is expected working gas volume underground gas storage will be from 2005 of 3300×10^8 m^3 grow to 5430×10^8 m^3 in 2030 on the globe scale.

The main growth areas of underground gas storage are still Europe, North America and the CIS countries. According to the forecast, the working gas of underground gas storage volume is from 790×10^8 m^3 in 2005 to 1350×10^8 m^3 in 2030. North America's working gas of underground gas storage volume is from 1160×10^8 m^3 in 2005 to 1870×10^8 m^3 in 2030 and CIS countries are from 1360×10^8 m^3 in 2005 increases to 1770×10^8 m^3 in 2030. Three traditional underground gas storage areas will remain the key point of growth of underground gas storages for the future demand. Due to the constraints of natural gas pipeline network system and underground geological conditions of gas storage construction in Asia Pacific area, and Japan, South Korea and other traditional natural gas market are dominated by LNG, so the underground gas storage growth rate in this area will not increase a lot, and proportion of these areas will account still less than 1% than overall global underground gas storage working gas volume.

According to the IGU analysis of underground gas storage, the future demand driving growth force mainly comes from the following aspects:

1) Lots of countries start to pay attention to natural gas strategic reserve. Russia, as the representative of these countries, already has begun to increase natural gas strategic reserve.

2) The change of natural gas supply mode. LNG trading has big impact on traditional pipeline natural gas market, which will stimulate the demand for underground gas storage.

3) The short term natural gas trade needs. Short term trading requires underground gas storage as an effective turnover.

4) Network system needs further balance, including the balance of the conveying capacity and pressure balance.

5) Oil development leads to a large number of associated gas emissions which will cause atmospheric pollution, so construction of underground gas storage will also need to meet the needs of associated gas storages.

Specific to different areas, the main driving forces of underground gas storage are also different. The demand growth of underground gas storage in Western Europe countries comes mainly from the increase of dependence on natural gas import countries. Counties which have high natural gas dependence on foreign countries must build underground gas storage system to meet the need of natural gas reserves. In Europe case, according to the IGU experience, once the natural gas external dependence has achieved more than 30%, and then the working gas of underground gas storage volume would need to exceed more than 12% of natural gas consumption volume. If the gas dependence on foreign countries is more than 50% then most of the working gas of underground gas storage volume will exceed 20% of natural gas consumption. For instance, France, Austria and so on reached about 30%. With the decline of local natural gas production and growth of dependence on import natural gas in Western European countries, the demand of the gas underground storage will be increasingly urgent in the future.

Underground gas storage demand growth patterns in North American area rely mainly on unconventional natural gas development. Especially in the United States, because of the new large-scale unconventional natural gas development, it not only changed the regional natural gas supply and demand balance, but also changed the local supply direction of natural gas flow. The new underground gas storage construction needs mainly meet the unconventional natural gas development and utilization as well as adaptation and assure the unconventional natural gas supply, peak-shaving.

CIS countries, due to influence of geopolitics and national economic development, start to add efforts in protection of local gas supply also increase their underground gas storage construction efforts and inputs.

VIII. CONCLUSION

China’s construction of underground gas storage is in the early stages of development, although its underground gas storage construction is faced with many challenges, but once pay enough attention to the important and indispensable position of underground gas storage in the natural gas industry, meanwhile pay attention to digest and absorb foreign advanced experience and technology, through technical innovation and management creation, and constantly increase construction strength. Then underground gas storage in China will boom along with the rapid development of natural gas business which plays an irreplaceable important role in stabilization and secure gas supply.

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World natural gas Summit the most important event of International Gas Union (IGU), which is held every 3 years at the country of chairman of the IGU, and it is the world's highest level event of natural gas industry.

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